Published online October 19, 2005

Influence of Sowing Date on Emergence Characteristics of Maize Seed Coated with a Temperature-Activated Polymer

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ABSTRACT

Cold, wet soils, coupled with a short growing season, create a narrow window of optimum time for planting corn (*Zea mays* L.) in the northern Corn Belt. Temperature-activated polymer (TAP) coatings designed to inhibit planted seed from imbibing water until adequate soil temperatures are reached to promote germination and emergence may offer potential for planting corn exceptionally early. A study from 2000 to 2002 was conducted in west central Minnesota on a Barnes soil (Calcic Hapludoll) to determine the potential for earlier-than-average planting of TAP-coated corn seed. The objective was to compare emergence characteristics of coated and uncoated hybrid corn planted early and at a near-average planting date. Seed planted 29 Mar. 2000 and 24 Apr. 2002 remained in the soil for as long as 26 to 32 d before emerging. In these instances, stands from TAP-coated seed, which ranged from 60 to 90% of seed planted, were generally greater than those of uncoated seed, which ranged from 49 to 68%. Stand establishment and time required to obtain 50% and from 10 to 90% emergence for most early planted coating × hybrid seed combinations were similar to uncoated seed planted at near-average planting dates of 1, 14, and 16 May in 2000, 2001, and 2002, respectively. When both coated and uncoated seed were sown at an average planting date, stand establishment was similar, but emergence for coated seed was generally delayed. Results of this study indicate that TAP coatings protected seeds from injury caused by extended exposure to cold soils, and therefore, might be a useful management tool for early corn planting.

The northern Corn Belt of the USA is characterized by a short growing season. Therefore, the timing of field operations for crop production is critical. Due to a short growing season and slow warming and drying of soils in the spring, the optimum period for planting can be quite narrow. Sowing corn as early as possible ensures taking advantage of the entire growing season, thus allowing the use of full-season hybrids to optimize yields (Lauer et al., 1999). In the central Corn Belt, typically the optimum time to plant corn is late April to early May (Benson, 1990). Based on soil temperature and moisture requirements necessary to obtain 75% corn emergence within 14 d, Gupta (1985) recommended that corn in the northern Corn Belt typically be planted within approximately the first 7 to 14 d of May. For a 4-yr study conducted at six different locations in Wisconsin, Lauer et al. (1999) found that the optimum times to plant corn for best grain yields ranged from 1 to 7 May in the southern part of the state and 8 to 14 May for the northern part of the state. In terms of grain yield, the optimum time for planting corn in southern Minnesota is considered to be late April to early May (Hicks et al., 1977). Although in some years soil temperatures are warm enough to plant corn as early as 20 April in southern Minnesota and 25 April in northern parts of the state, generally about 50% of the land area devoted to corn production is sown by May 11 (Hardman and Gunsolus, 2002). Delaying corn planting beyond an optimum period can result in substantial yield loss. It has been suggested that in Minnesota, for each day corn seeding is delayed between 1 May and the end of the month, there is approximately 0.5% d^{-1} yield loss (Hardman and Gunsolus, 2002).

One of the greatest barriers preventing early corn planting in the northern Corn Belt is cold, wet soils. This can be problematic where heavy soils predominate and conservation tillage practices are used (Gupta et al., 1988; TeKrony et al., 1989). Temperature is the primary factor affecting corn germination and seedling emergence, although soil moisture is also an important factor (Schneider and Gupta, 1985). During spring planting in the northern fringes of the Corn Belt, soils are often at or near field capacity for moisture (Dwyer et al., 2000). Therefore, lack of soil moisture is typically not a primary deterrent of emergence. Planting corn too early can result in seeds imbibing water but not germinating for long periods due to soil temperatures that are too low. Consequently, this can lead to a weakening of seed and seedling development caused by soil microbes, which are active even at temperatures not conducive to corn germination (Shaw, 1977). The result can be poor stand establishment, uneven emergence, and slow plant development (Gupta et al., 1988; Ford and Hicks, 1992; Bollero et al., 1996).

The accepted minimum temperature for corn seed germination is about 10°C (Shaw, 1977). Blacklow (1972) showed that seedling radicle and shoot elongation rates were greatest, and time to initiation the least, at about 30°C. It was also found that both processes for corn essentially ceased at constant temperatures of 9 and 40°C. Temperature-responsive polymer seed coatings have been developed that may allow early corn planting while reducing risks of seed injury associated with cold, wet soils (Hicks et al., 1996). This temperature-activated polymer (TAP) coating (Intellicoat, Landec Ag, Menlo Park, CA) is created using a process of side-chain crystallization of *n*-alkyl polyacrylates (Greenberg and Alfrey, 1954). Acrylate polymers developed in this way are characterized by having well defined melting points. In a crystalline state, the polymer is highly impermeable to

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Published in Agron. J. 97:1543–1550 (2005).
Corn
doi:10.2134/agronj2005.0054

Abbreviations: DOY, day of year; GDD, growing degree days; TAP, temperature-activated polymer; UN, uncoated seed.

water, but once a critical temperature is reached the physical structure becomes amorphous and hence permeable (Hicks et al., 1996; Landec Ag, 2004). Furthermore, the process is reversible on cooling. The purpose of the temperature-activated polymer coating for early planted seed is to restrict imbibition of water until the soil has reached an adequate temperature to promote ideal germination and subsequent emergence, thus, potentially reducing injury associated with cold, wet soil. Using simulation modeling, Archer and Gesch (2003) estimated the value of early planted TAP-coated corn and soybean [*Glycine max* (L.) Merr.] on two tillage systems, two soil types, and varying weather conditions for a representative farm in Minnesota. Results indicated that TAP-coated seed can potentially increase net returns by increasing yields due to early sowing. This allows the greater use of full season hybrids, and reduces yield-loss associated with delayed planting. Additionally, TAP coating technology potentially can extend the period for planting, allowing producers more flexibility for utilizing limited equipment and labor in completing spring field operations.

Although laboratory tests indicate that TAP coating retards water uptake by seeds at low temperatures (Hicks et al., 1996), extensive field research is needed to determine the feasibility of using this technology for earlier than normal planting. The present study was designed to compare the emergence performance and characteristics of TAP-coated vs. uncoated hybrid corn seed when planted early into cold ($\leq$10°C) soils, and at a near-average planting date under warmer (>10°C) soils for west central Minnesota. The primary hypothesis tested was whether TAP-coated seed planted early under cold soil conditions results in stand establishment and uniformity comparable to that of uncoated seed planted under more favorable soil temperatures.

MATERIALS AND METHODS

Plant Culture and Emergence

The study was conducted in 2000, 2001, and 2002 at the Swan Lake Research Farm located 24 km northeast of Morris, MN (45°40′ N lat) on a Barnes soil (fine loamy, mixed, superactive, frigid Calcic Hapludoll). The experimental design was a split-plot randomized complete block with four replications. The main plots were planting dates and split plots were a factorial arrangement of hybrid × coating treatments completely randomized within each planting date plot. In 2000, each treatment split plot consisted of six rows spaced 0.76 m apart by 9.14 m long. In 2001 and 2002, row lengths were increased to 13.72 m. In all 3 yr, corn was sown on ground previously cropped with soybean. The seedbed was chisel-plowed the previous fall and harrowed before planting. Fertilizer was incorporated into the top 0.15 m of soil before planting at a rate of 168, 39, and 39 kg ha^{-1} N, P, and K, respectively. Phosphorous was added as diammonium phosphate and K as potassium oxide. Nitrogen was added as urea (152.6 kg ha^{-1}) and diammonium phosphate (15.4 kg ha^{-1}). No weed control was applied until several days after plants had fully emerged to avoid potential herbicide effects on emergence. Corn was planted on 29 March, 14 April, and 1 May in 2000. Because of wet soil conditions in 2001 and 2002, the earliest planting dates those 2 yr were 30 April and 24 April, respectively. A second planting was made in 2001 and 2002 on 14 May and 16 May, respectively. Seeds were sown at a rate of 74 134 ha^{-1} and at a depth of 0.05 m with a six-row John Deere planter equipped with a cone type seeder. In all 3 yr Fielder's Choice brand hybrids 8195 (95 d maturity) and 9198 (98 d) were grown; in 2001, a third hybrid, 9301 (101 d), was added.

The temperature-activated polymer coatings used in this study were manufactured and applied to seeds by Intellicoat Corporation (a division of Landec Ag, Menlo Park, CA). The coatings consisted of a poly-acrylate base, with an activation temperature of approximately 12°C. All seeds were treated with a mix of Captan (*N*-(trichloromethylthio)cyclohex-4-ene-1,2-dicarboximide), Thiram (tetramethylthiuram disulfide), and Metalaxyl (methyl *N*-(methoxyacetyl)-*N*-(2,6-xylyl)-DL-alaninate) before coating; uncoated seed (UN) was only treated with the fungicide mix. Coatings designated as A and B in this study differed by weight of the coating applied to seed. Coating A consisted of approximately 20 g polymer kg^{-1} seed weight, while coating B was approximately 30 g kg^{-1} in 2000 and 25 g kg^{-1} in 2001 and 2002. New seed was received and used each year for the study. Laboratory germination tests at 25°C verified that germination was 98 to 100% for both coated and uncoated seeds each year. In 2001, no A-coated seeds for hybrids 8195 and 9198 were received. Seedling emergence was measured about every 2 d in 4.6 m of one of the center rows of each treatment plot until counts no longer changed. The same length of row was used each time a count was made. Seedlings were counted as emerged when the coleoptile was at least 0.01 m or greater above the soil surface. Emergence is expressed as percentage of seed sown and as a function of accumulated growing degree days (GDD). For GDD calculations, soil temperatures at the seeding depth (0.05 m) were used. Accumulated GDD were calculated as: $\Sigma T_{avg} - B$; where T_{avg} is the average daily 0.05-m soil depth temperature and B is a base temperature of 10°C. Accumulation of GDD commenced on the day of planting.

Soil Temperature Measurements

Thermocouple arrays were installed within 48 h after the first planting. At least two arrays were installed per replicated block for a total of eight. In 2000, one thermocouple array in each of two replications malfunctioned and therefore data from those replicates were not included. Each thermocouple array was constructed of three 24-gauge copper/constantan junctions threaded through a 120 mm long by 40 mm wide by 12 mm thick block of PVC and then into 4 mm diameter by 70 mm long stainless steel probes mounted at 0.01, 0.05, and 0.10 m along the long edge of the PVC. The probes were filled and sealed with high thermal conductivity epoxy (Omegabond, Omega, Stamford, CT). The arrays were installed vertically with the top of the PVC block flush with the soil surface so that the probes were at 0.01, 0.05, and 0.10 m below the soil surface. For field placement, a vertical slab of soil was removed approximately 0.10 m from the side of where seeds were planted, the array was pushed into place so as to not disturb the soil within the seed zone, and the slab was replaced and packed firmly. Temperature measurements were monitored with a CR10X data logger (Campbell Scientific, Logan, UT) every 60 s, and 15-min averages were recorded. At 0000 h (midnight) Central Standard Time the daily minimum, maximum, and mean temperatures were recorded based on the 15-min averages.

Statistical Analysis

Nonlinear regression using GraphPad Prism (GraphPad Software, San Diego, CA) was used to fit the data to a Boltzmann sigmoidal function of the form:

$$Y = A/\{1 + \exp[2 \times \ln(9) \times (E_{50} - \mathrm{GDD})/B]\}$$

where Y is emergence percentage of seed sown, GDD is accumulated growing degree days, A is maximum emergence, E_{50} is growing degree days from sowing to 50% of maximum emergence, and B is growing degree days from 10 to 90% of maximum emergence. Two-way ANOVA, also using GraphPad Prism (GraphPad Software, San Diego, CA), was used on the parameter estimates to determine whether there were significant differences among planting dates and coatings within each hybrid and year. In cases where significant differences were detected, Bonferroni posttests were used for mean separation.

RESULTS

There was no significant hybrid effect ($P \leq 0.05$) on stand establishment for any of the 3 yr. The hybrid × planting date interaction was only significant in 2002, when 9301 generally had greater seedling emergence than the other two hybrids in the first planting date. Over the 3-yr study, TAP coating and planting date affected emergence characteristics for the hybrids examined. Due to variations in planting dates and soil temperatures, data were analyzed separately for each year. For the earliest planting dates in 2000 and 2002, seeds remained in the soil for a considerable amount of time (as much as 32 d) before emerging (Fig. 1 and 3). For the later planting dates in all 3 yr, and for the first planting date in 2001, emergence occurred much sooner after planting (Fig. 1–3).

Days to Emergence

In 2000, daily mean 0.05-m depth soil temperature remained <10°C until day of year (DOY) 113 (Fig. 1). Seeds sown on 29 March were exposed to soil temperatures <10°C for 24 d, while those sown on 14 April were exposed to cold temperatures for 8 d before emerging (Fig. 1). By DOY 122 (1 May), soil temperature at 0.05 m was >10°C (Fig. 1). For the first two planting dates in 2000, there was little difference in the date of initial emergence between coated and uncoated seed. In the 1 May planting, emergence of 9198 B was delayed compared with other hybrid × coating combinations. This response may have been due to cold weather between Days 131 and 134, during which soil temperature decreased to <10°C before initial emergence of 9198 B.

In 2001, by 30 April, soil temperatures had warmed to at least 10°C and only 1 d separated initial emergence of 8195 coating B and 9301 coating A from that of the other treatments (Fig. 2). Daily mean soil temperatures were as low as 8°C between DOY 141 and 144 in 2001 at which time coated seed of all three hybrids in the second planting had not yet emerged (Fig. 2). The initial emergence of coated seed ranged from 4 to 10 d later than uncoated controls in the second planting date similar to 9198 coating B for the latest planting date in 2000.

During 2002, seeds sown 24 April were exposed to mean soil temperatures at or below 10°C for 20 d (Fig. 3). The longest delay to initial emergence for the first planting date in 2002 was for uncoated seed of 9198 (29 d from sowing to emergence). Mean soil temperature was 12.4°C at the time of the second planting in 2002 and remained above this temperature until seedlings of all hybrid and coating combinations had emerged (Fig. 3). For the 16 May planting in 2002, initial emergence of

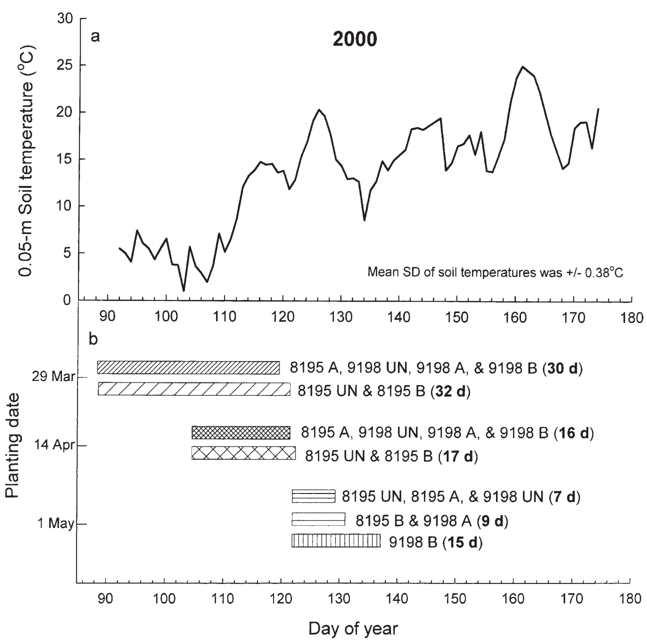

Fig. 1. (a) Daily mean soil temperatures at the 0.05-m depth as a function of day of the year for year 2000 and (b) time between planting and initial emergence for the various hybrid (8195 and 9198) and seed coating (A, light; B, heavy; and UN, uncoated) combinations used. The numbers in parentheses are the number of days between planting and initial emergence. Initial emergence is the time at which emergence was first noted for a particular hybrid × coating combination.

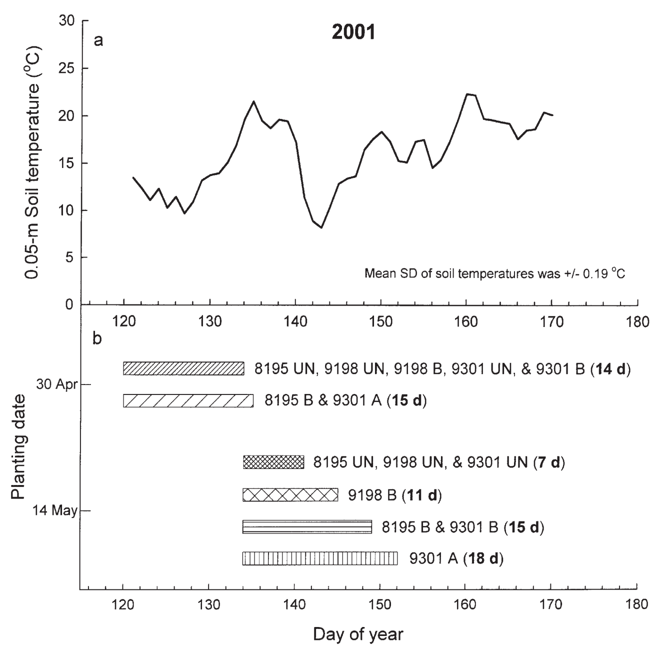

Fig. 2. (a) Daily mean soil temperatures at the 0.05-m depth as a function of day of the year for year 2001 and (b) time between planting and initial emergence for the various hybrid (8195, 9198, and 9301) and seed coating (A, light; B, heavy; and UN, uncoated) combinations used. The numbers in parentheses are the number of days between planting and initial emergence. Initial emergence is the time at which emergence was first noted for a particular hybrid × coating combination.

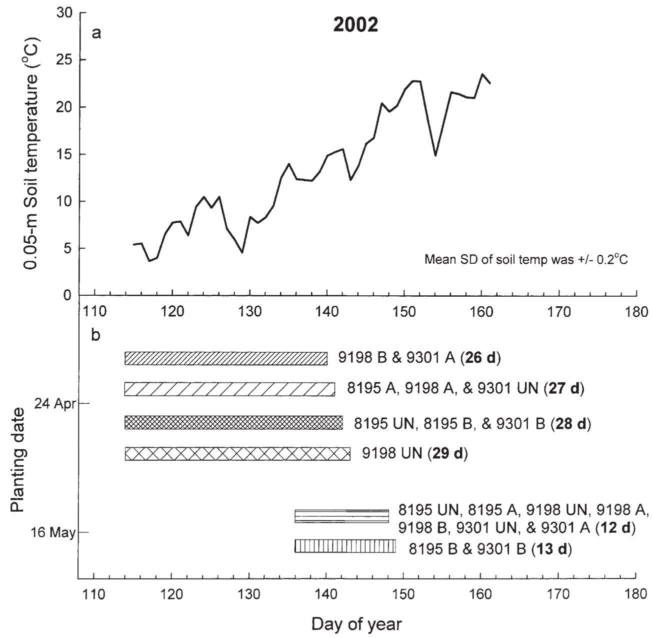

Fig. 3. (a) Daily mean soil temperatures at the 0.05-m depth as a function of day of the year for year 2002 and (b) time between planting and initial emergence for the various hybrid (8195, 9198, and 9301) and seed coating (A, light; B, heavy; and UN, uncoated) combinations used. The numbers in parentheses are the number of days between planting and initial emergence. Initial emergence is the time at which emergence was first noted for a particular hybrid × coating combination.

all hybrid and coating combinations occurred approximately the same time (Fig. 3).

Maximum Emergence

When planted 29 March in 2000, TAP-coated seed of both hybrids led to significantly greater stand establishment (i.e., maximum emergence) than uncoated seed (Table 1). For the second planting, differences in emergence between hybrids or coatings were not as great as observed during the first planting date. However, emergence of both 8195 and 9198 coating B was consistently greater than that of uncoated seed, but in the third sowing they were lower than uncoated controls (Table 1).

During 2001, no significant differences in stand establishment occurred between TAP-coated and uncoated seeds of any of the three hybrids tested for the 30 April planting date (Table 1). For the second planting date, 8195 B and 9301 A had significantly greater and lower maximum emergence, respectively, compared with uncoated seeds (Table 1). In 2002, both planting date and seed coating significantly influenced stand establishment similar to what occurred in 2000 (Table 1). In the first planting date, maximum emergence of hybrids 8195 and 9301 coatings A and B and 9198 coating B was greater than that of their uncoated counterparts (Table 1).

Growing Degree Days for 50% Emergence

Accumulated GDD (measured at the 0.05-m depth) between sowing date and 50% emergence allows for comparisons of seedling emergence rates for the various hybrid and seed coating treatments between planting dates. The number of GDD between sowing and 50% emergence increased with planting date for each hybrid × coating treatment (Table 2). For the 29 March and 14 April planting dates in 2000, the number of GDD to reach 50% emergence was similar between coated and uncoated seed of 8195 (Table 2). For 9198, the number of GDD to 50% emergence was slightly less for coated than uncoated seed in the first planting date. For both hybrids in the third planting date, the accumulated GDD to reach 50% emergence was greater for TAP-coated seed than that of uncoated controls, with the heavier B coating causing slower emergence than the lighter A coating (Table 2).

In 2001, the number of GDD from sowing to 50% emergence for all hybrids and planting dates was consistently greater for TAP-coated seed than uncoated con-

Table 1. Maximum emergence for the various hybrid and seed coating treatments at different planting dates. Values are means, $n = 4$. Letters a, b, and c compare values within rows for a given hybrid and planting date for each year and letters x, y, and z compare values within columns for a given hybrid and coating. Values followed by the same letter within rows or columns are not different at the $P \leq 0.05$ level.

Planting date†	Year and seed coating								
	2000			2001			2002		
	UN	A	B	UN	A	B	UN	A	B
	% of seed sown								
				Hybrid 8195					
1	49.1 by	87.3 ax	89.9 ax	86.9 ax	–	82.9 ay	52.8 by	75.3 ay	77.7 ay
2	86.4 bx	89.5 abx	93.8 ax	87.0 bx	–	95.7 ax	85.9 ax	90.5 ax	91.8 ax
3	89.7 ax	85.1 abx	81.2 by	–	–	–	–	–	–
				Hybrid 9198					
1	73.7 cy	82.5 by	90.3 ax	82.0 ay	–	85.9 ay	53.1 by	60.1 by	76.9 ay
2	88.0 bx	88.9 abx	94.1 ax	90.0 ax	–	94.3 ax	93.8 ax	92.0 ax	92.1 ax
3	89.2 ax	87.8 ax	81.7 by	–	–	–	–	–	–
				Hybrid 9301					
1	–	–	–	94.5 ax	92.6 ax	90.0 ax	68.2 by	80.4 ay	85.3 ax
2	–	–	–	92.8 ax	86.3 by	92.2 ax	86.4 ax	90.3 ax	88.9 ax

† Planting dates 1, 2, and 3 in 2000 were 29 March, 14 April, and 1 May, respectively; planting dates 1 and 2 in 2001 were 30 April and 14 May, respectively; and planting dates 1 and 2 in 2002 were 24 April and 16 May, respectively.

Table 2. Number of accumulated growing degree days (GDD) between sowing and 50% emergence dates for the various hybrid and seed coating treatments at different planting dates. Values are means of accumulated GDD at the 0.05-m soil depth (°C d, base of 10°C), $n = 4$. Letters a, b, and c compare values within rows for a given hybrid and planting date for each year and letters x, y, and z compare values within columns for a given hybrid and coating. Values followed by the same letter within rows or columns are not different at the $P \leq 0.05$ level.

Planting date†	Year and seed coating								
	2000			2001			2002		
	UN	A	B	UN	A	B	UN	A	B
	°C d								
	Hybrid 8195								
1	42.6 az	41.6 az	41.2 az	46.1 by	–	58.3 ay	22.7 ay	13.9 by	13.5 by
2	54.8 ay	50.8 ay	52.8 ay	59.5 bx	–	89.2 ax	31.3 cx	60.7 ax	52.7 bx
3	63.5 cx	82.2 bx	97.7 ax	–	–	–	–	–	–
	Hybrid 9198								
1	39.4 ay	35.4 bz	35.1 bz	49.9 by	–	57.3 ay	26.8 ax	20.2 by	11.8 cy
2	42.3 ay	44.6 ay	43.9 ay	59.3 bx	–	87.5 ax	31.4 cx	36.7 bcx	48.1 ax
3	62.7 cx	90.9 bx	101.2 ax	–	–	–	–	–	–
	Hybrid 9301								
1	–	–	–	45.6 by	62.0 ay	59.6 ay	11.8 ay	12.4 ay	13.2 ay
2	–	–	–	61.1 cx	102.2 ax	96.2 bx	31.3 cx	44.1 bx	61.2 ax

† Planting dates 1, 2, and 3 in 2000 were 29 March, 14 April, and 1 May, respectively; planting dates 1 and 2 in 2001 were 30 April and 14 May, respectively; and planting dates 1 and 2 in 2002 were 24 April and 16 May, respectively.

trols, and this difference increased with later planting (Table 2). In 2002, accumulated GDD between sowing and 50% emergence for TAP-coated seed of 8195 and 9198 was less than uncoated controls for early planting and greater than untreated controls in the second planting date (Table 2). Like the other two hybrids, coated seed of 9301 sown late, also showed a greater delay in reaching 50% emergence than the uncoated counterpart (Table 2).

Stand Uniformity

Accumulated GDD between 10 and 90% emergence allows comparisons of emergence rates as influenced by the interaction between soil temperature and the various hybrid/seed coating treatments. It is an indicator of stand uniformity. The lower the accumulated GDD between 10 and 90% emergence the more likely the stand is to be uniform. The total number of GDD between 10 and 90% emergence for coated and uncoated seed of 8195 in the first two planting dates of 2000 was similar, but it was greater for coated than uncoated seed for the third sowing date (Table 3) implying a less uniform stand. Coated seed of 9198 in the early sowing reached 90% emergence sooner than the uncoated control. For 9198 in the third planting, only the A coating slowed 90% emergence (Table 3).

In 2001, accumulated GDD between 10 and 90% emergence was less for coated than uncoated seeds of both 8195 and 9198 planted early, but greater than control seeds when planted 14 May (Table 3). In the first planting date of 2002, the accumulated GDD between 10 and 90% emergence for coated seed was either the same or less than the uncoated controls, while in the later planting it tended to be greater (Table 3).

Table 3. Number of accumulated growing degree days (GDD) between 10 and 90% emergence dates for the various hybrid and seed coating treatments at different planting dates. Values are means of accumulated GDD at the 0.05-m soil depth (°C d, base of 10°C), $n = 4$. Letters a, b, and c compare values within rows for a given hybrid and planting date for each year and letters x, y, and z compare values within columns for a given hybrid and coating. Values followed by the same letter within rows or columns are not different at the $P \leq 0.05$ level.

Planting date†	Year seed coating								
	2000			2001			2002		
	UN	A	B	UN	A	B	UN	A	B
	°C d								
	Hybrid 8195								
1	21.3 axy	23.6 ay	19.9 ax	28.9 ax	–	11.9 by	23.6 ax	6.0 by	5.4 by
2	35.1 ax	30.0 ay	30.9 ax	5.3 by	–	34.7 ax	5.8 by	45.3 ax	28.0 ax
3	15.1 cy	57.2 ax	38.0 bx	–	–	–	–	–	–
	Hybrid 9198								
1	24.8 ax	11.8 by	9.1 by	32.0 ax	–	12.7 by	33.8 ax	31.5 ax	7.8 bx
2	21.8 abx	25.0 ax	13.7 by	7.0 by	–	34.1 ax	6.1 ay	18.7 ax	22.0 ax
3	16.0 bx	29.9 ax	25.0 abx	–	–	–	–	–	–
	Hybrid 9301								
1	–	–	–	24.0 ax	12.4 ax	12.1 ay	6.0 ax	7.5 ax	4.5 ay
2	–	–	–	5.7 by	18.2 bx	40.6 ax	5.7 cx	21.5 bx	36.2 ax

† Planting dates 1, 2, and 3 in 2000 were 29 March, 14 April, and 1 May, respectively; planting dates 1 and 2 in 2001 were 30 April and 14 May, respectively; and planting dates 1 and 2 in 2002 were 24 April and 16 May, respectively.

Temperature-Activated Polymer vs. Uncoated Seed Emergence Characteristics

To fully assess the potential benefits of TAP coatings for early planting it is important to directly compare emergence characteristics of coated seed planted early with that of uncoated seed planted at a normal or average date. In 2000, maximum emergence of the earliest planted 8195 A, 8195 B, and 9198 B did not differ from that of uncoated seeds sown 1 May (Table 4). Maximum emergence of early planted 8195 B in 2001 was lower than its uncoated control sown 14 May, but the other early hybrid coating treatments were not different than their respective uncoated controls planted later (Table 4). During 2002, early planted TAP-coated seed of 8195 and 9198 resulted in lower maximum emergence than their respective uncoated controls planted 16 May (Table 4). However, early sown 9301 A and 9301 B resulted in similar maximum emergence to uncoated seed planted later.

In both 2000 and 2002, total accumulated GDD to 50% emergence for all hybrid TAP coating treatments in the earliest planting date were significantly less then uncoated controls in the latest planting date for each of those years (Table 4). In 2001, there was no difference in accumulated GDD to 50% emergence between coated seed planted early and uncoated seed sown 14 May for all hybrids (Table 4). During all 3 yr, nearly all TAP-coated hybrid combinations planted early resulted in a similar delay between 10 and 90% emergence when compared with their respective uncoated controls in the latest planting each year (Table 4). The only exceptions were 8195 A in 2000 and 9198 A in 2002, which had greater accumulated GDD between 10 and 90% emergence than their respective uncoated controls in the latest planting.

Table 4. Comparison of emergence attributes of TAP-coated hybrid corn seed in the earliest planting date for each year with that of its uncoated control counterpart seed sown at the latest planting date each year. NS, < , and > denote if emergence attributes were not significant, significantly less, and significantly greater than ($P \leq 0.05$) the corresponding uncoated seed planted at the latest planting date for the given hybrid. The earliest/latest plantings were 29 March/1 May, 30 April/14 May, and 24 April/16 May for 2000, 2001, and 2002, respectively.

Hybrid + coating	Maximum emergence	GDD to 50% emergence	GDD from 10 to 90% emergence
		2000	
8195 A	NS	<	>
8195 B	NS	<	NS
9198 A	<	<	NS
9198 B	NS	<	NS
		2001	
8195 B	<	NS	NS
9198 B	NS	NS	NS
9301 A	NS	NS	NS
9301 B	NS	NS	NS
		2002	
8195 A	<	<	NS
8195 B	<	<	NS
9198 A	<	<	>
9198 B	<	<	NS
9301 A	NS	<	NS
9301 B	NS	<	NS

DISCUSSION

When hybrid corn seed was planted into soil <10°C and remained in the soil for >20 d before beginning to emerge, maximum emergence was almost always greater for coated seed than that of uncoated seed (Fig. 1 and 3 and Table 1). Furthermore, based on seed zone GDD, often the rate of emergence was more rapid for coated seed than uncoated seed when both were exposed to cold soil for >20 d (Tables 2 and 3). These results indicate that TAP coatings offered some protection against injury caused by cold soil. The longer seed remains in the ground under cold soil conditions before emergence the more likely it is to be damaged by pathogens, thus leading to poor stand establishment (Shaw, 1977). Although not measured in this study, the coatings probably offered protection to seeds by restricting water imbibition until soil temperatures increased to levels more conducive to germination.

An important concern regarding the usefulness of TAP-coatings for early planting is how emergence of coated seed exposed to cold soil (i.e., ≤10°C) for an extended time compares with uncoated seed planted when soil temperatures are more favorable for germination. Results for this comparison differed among years. In 2000, stand establishment of TAP-coated seed for hybrids 8195 and 9198 planted 29 March was similar to that of uncoated seed planted 1 May. However, in 2002, TAP-coated seeds of the same two hybrids planted 24 April resulted in poorer stands compared with the stands of uncoated seed planted 16 May. These different responses for coated seeds observed between years may have been caused by differences in soil moisture. Total precipitation in April of 2000 at the study site was 0.8 mm, 55.8 mm below average, while precipitation in April of 2002 was closer to average at 45.7 mm. The presumably greater soil water content in the spring of 2002 possibly interacted with the coatings, causing them to deteriorate. This allowed seeds to imbibe water while soil temperatures were too low to promote germination, thus leading to some injury. Alternatively, because seed was coated new each year, there may have been differences in the coating application between years, leading to the differing results observed for hybrids 8195 and 9198. In 2002, there was also a hybrid difference, as the early planted 9801 seed generally resulted in stands greater than hybrids 8195 and 9198 sown at the same planting date. The reason for this difference may be due to greater cold tolerance and/or seed vigor in hybrid 9801 as compared with the other hybrids. Therefore, success of early planting TAP-coated corn may be somewhat dependent on hybrid genetics, but this requires further study.

Uneven corn emergence can often lead to lower yields (Nafziger et al., 1991). In this study, uneven emergence was not apparent with either uncoated or TAP-coated seed (field observation). However, differences in emergence rate based on GDD did develop among coated and uncoated seed and between planting dates (Tables 2 and 3). Generally, when hybrid corn seed remained in the soil for an extended time due to cold temperatures (e.g., 2000 and 2002), TAP-coated seed had more rapid emergence rates than uncoated seed. Furthermore, when compared with uncoated seed planted in early to mid-May, earlier-sown coated seed generally had similar or greater rates of emergence (Table 4). Again, these results indicate that the TAP coatings may have offered some protection against cold soils allowing seed to retain vigor until germination.

For the near-average planting dates, the emergence rate of coated compared with uncoated seed responded differently than in the early plantings. In these instances, TAP coatings generally resulted in slower emergence rates than uncoated seed, and therefore, may have had a detrimental effect for sowing at an average planting date. In fact, the longer emergence delay, especially that between 10 and 90% emergence, indicates the potential for uneven emergence. The reason for this is likely the time required for the coating to dissociate before allowing water absorption, which might be influenced by soil type and soil water content. In laboratory germination studies, Hicks et al. (1996) showed that even at 25°C, TAP-coated hybrid corn seed, over a 48-h period, imbibed water more slowly than uncoated seed.

For the latest planting dates, initial emergence of coated seed (e.g., 9198 coat B and 9301 coat A) was as much as 8 to 11 d later than uncoated controls in 2000 and 2001 (Fig. 1 and 2). However, it should be noted that in both 2000 and 2001, cold weather caused soil temperatures to drop sharply after the latest planting. In 2001, coated seed of all three hybrids had not yet emerged when the soil temperature dropped to as low as 8°C. Although not measured in this study, it is possible that during this time the polymer coating may have reverted back to its crystalline state, or its dissociation was simply delayed, thus slowing water absorption and seed germination. In 2002, soil temperatures after planting continued to gradually increase until emergence, resulting in little difference in initial emergence between coated and uncoated seed of all three hybrids.

CONCLUSIONS

Temperature-activated polymer seed coating technology may potentially be a useful management tool for allowing earlier than normal planting of corn in the northern Corn Belt without loss of stand and yield potential. Benefits of planting 2 to 4 wk earlier than average include reducing the risk of yield-loss due to late planting (Archer and Gesch, 2003). In addition, planting earlier than normal may allow producers more flexibility for utilizing limited equipment and labor in completing spring field operations. Caution, however, must be taken when planting early in the northern Corn Belt region. If soils are too wet at the time of planting, heavy equipment can cause soil compaction that can persist across growing seasons (Voorhees et al., 1978). Also, if warm early spring conditions lead to early emergence, seedlings may face an increased risk of damage due to frost.

In this study, temperature-activated polymer-coated hybrid corn seed planted as much as 4 to 5 wk earlier than average generally produced stands comparable to that of uncoated seed planted at an average time under more favorable soil temperatures. However, when coated seed was planted at a near-average planting date, its emergence rate was often slower than that of uncoated seed. This delay in emergence caused by the coating could potentially lead to uneven stands and loss of yield potential by shortening the length of time for vegetative plant development. In the future, planting date guidelines will likely need to be made for when to switch from planting TAP-coated to uncoated seed. Further research is needed to evaluate TAP coating on a wider range of hybrids than used in this study. Also, our results indicate that more research is needed to assess potential interactions of soil temperature, water content, and soil type on the physical characteristics of TAP coating in relation to corn seed germination.

ACKNOWLEDGMENTS

The authors thank Joe Boots, Laurel “Skip” Maanum, and Charles Hennen for expert field assistance. We also thank Intellicoat (Landec Ag) for supplying and coating the seeds used in this study.

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